

# Chapter 4

## Eelgrass & Cordgrass





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#### 4.0 EELGRASS AND CORDGRASS PILOT RESTORATION PROGRAM

The physical restoration of Batiquitos Lagoon produced elevations and a tidal prism suitable to support two important habitat-forming species: eelgrass (*Zostera marina*) and Pacific cordgrass (*Spartina foliosa*).

Eelgrass is a native marine vascular plant indigenous to the soft-bottom bays and estuaries of the Northern Hemisphere. It is a defining habitat-forming species for much of the shallow-subtidal elevations in southern California estuaries and shallow bays. Within the southern portion of its range, eelgrass growth is generally limited at the shore by desiccation stress at low tides. Throughout its range, eelgrass is generally limited along its deeper fringe by light reduction to a level below which photosynthesis is unable to meet the metabolic demands of the plant to sustain net growth. Eelgrass creates unique biological environments when it occurs in the form of submerged or intertidal aquatic beds or larger meadows.

Eelgrass plays many important roles in estuarine systems. It clarifies water through sediment trapping and stabilization (de Boer 2007). It also provides the benefits of nutrient transformation and water oxygenation (Yarbro and Carlson 2008). Eelgrass serves as a primary producer in detritus-based food webs (Thresher et al. 1992) and is further directly grazed upon by invertebrates, fish, and birds (Valentine and Heck 1999), thus contributing to eco-system health at multiple trophic levels. Additionally, it provides physical structure in the form of habitat to the community and supports epiphytic plants and animals, which are in turn grazed upon by other invertebrates, fish, and birds. Eelgrass is also a nursery area for many commercially and recreationally important finfish and shellfish (Heck et al. 2003), including both those that are resident within the bays and estuaries, as well as oceanic species that enter the estuaries to breed or spawn. Among recreationally important species, sand basses and lobster make use of eelgrass beds as habitat. Besides providing important habitat for fish, eelgrass and associated invertebrates provide important food resources, supporting migratory birds during critical life stages, including migratory periods.

Pacific cordgrass is a coastal salt marsh species native to California and northern Baja California (Hickman 1993). Pacific cordgrass exerts significant influence over biotic and abiotic factors within its canopy (Whitcraft and Levin 2007), providing habitat and resources for benthic and epibenthic communities. Cordgrasses are an important source of organic carbon for detritivores (Graca et al. 2000) and ultimately support a diverse and abundant array of invertebrates within salt marsh habitat (Levin et al. 1998).

Pacific cordgrass is part of an important transitional habitat between marine and upland habitats. Although it can survive low salinity environments, it is a poor competitor and exists within a salinity range that many terrestrial, high marsh, and freshwater marsh plants cannot tolerate. Thus, it exists within a narrow range along the shoreline where it is limited by competition at its upper boundary and by physical stress from inundation at its lower boundary. While its growth may be localized within narrow physical and biological limits, its influence extends to adjacent habitats. The carbon produced by cordgrass makes its way through detritus-based food webs and is ultimately transported to adjacent habitats where it provides energetic support for marine fishes and birds (Adam 1990).



Although cordgrass-dominated coastal salt marsh plays an important energetic role in marsh communities, it is most valued in southern California as habitat for the endangered light-footed clapper rail (*Rallus longirostris levipes*). Clapper rail numbers declined precipitously during the last century as marshes were filled and degraded (Unitt 2004). Pacific cordgrass provides important clapper rail nesting habitat (Massey et al. 1984). Thus, restoration of marsh habitats, and Pacific cordgrass in particular, is an important component in the recovery of the light-footed clapper rail.

The physical restoration of Batiquitos Lagoon created large areas suitable for the establishment of eelgrass and cordgrass. Pilot transplants of these two species were undertaken to further explore the factors relevant to a successful planting of eelgrass and cordgrass habitat in embayments with recently restored tidal influence and hopefully expand these two habitats through their introductions at Batiquitos Lagoon. This chapter describes the transplant methods used and the resulting distribution of the two species, with an emphasis on the effectiveness of restoration, trends in eelgrass and cordgrass coverage and health, the current status of the species, and management options to preserve or enhance these species on a long-term basis. For the reasons detailed in Chapter 1, all area measurements specified in this chapter will be reported in English units (square feet and acres).

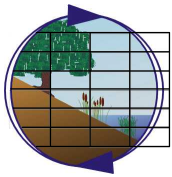
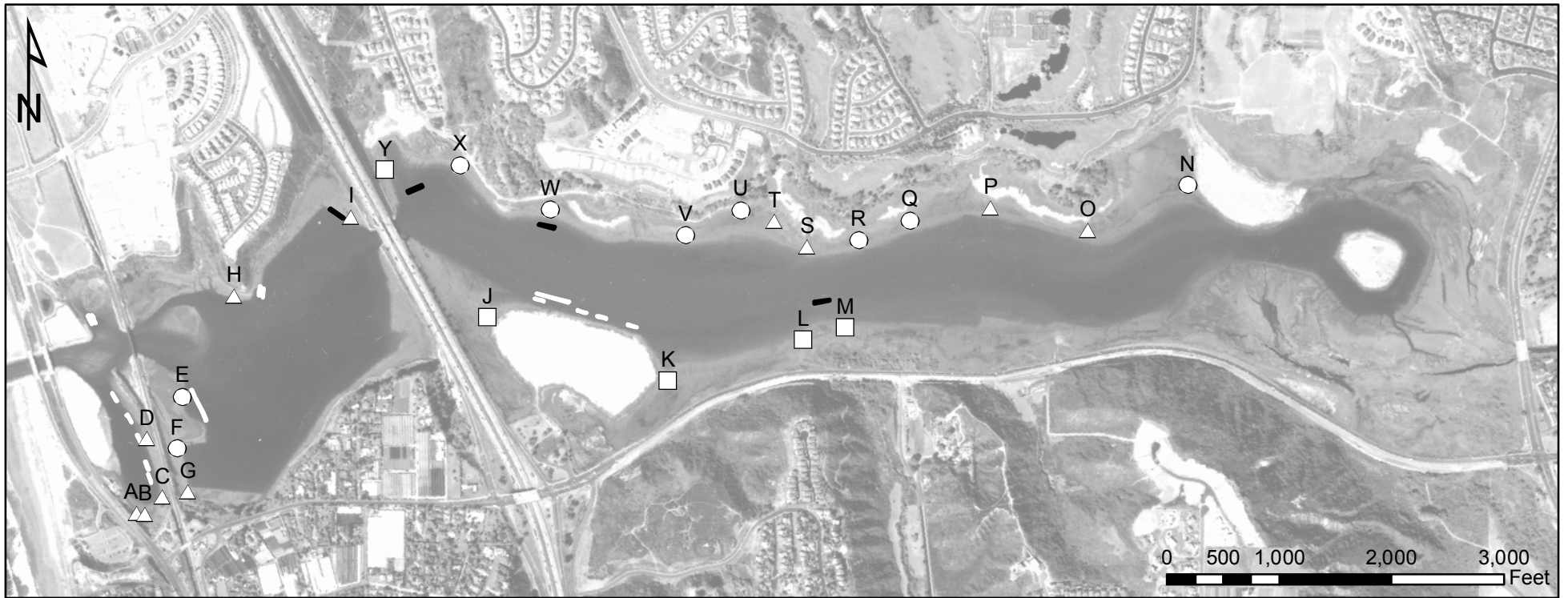
## 4.1 METHODS

### 4.1.1 Eelgrass Transplant

A pilot eelgrass transplant was conducted by Merkel & Associates (M&A) from September 26 to October 2, 1997 in the first year following the opening of the lagoon. Eelgrass transplants were originally proposed for the second year post-restoration to allow the lagoon sediments to stabilize. During the second quarter monitoring surveys of 1997, however, it was determined that various shoreline portions of the west, central, and east basin were consolidated enough to allow eelgrass to establish and persist. It was also anticipated that the presence of even a small amount of eelgrass could improve the capacity for the lagoon to support fish and invertebrate species that would be entering the lagoon. The selected transplant sites are shown in Figure 4-1. Each planting area covered approximately 1,600 ft<sup>2</sup>.

Donor eelgrass was harvested by SCUBA divers from three sites: Crown Point Shores in Mission Bay (adjacent to the Northern Wildlife Reserve), Glorietta Bay in San Diego Bay, and Agua Hedionda Lagoon in Carlsbad. Harvested eelgrass was processed into bare-root transplant units consisting of 8 to 12 healthy turions bundled together with a biodegradable soft anchor (Merkel 1987, 1990). Temporary planting lines were established within Batiquitos Lagoon in the areas described above. The plant materials were planted along temporary planting lines deployed at each transplant location. The biodegradable anchor was buried parallel to the sediment surface and the root/rhizome bundle was planted approximately two to three inches below the sediment surface. Planting units were spaced at 3.3-foot intervals. The planting lines were removed at the completion of the transplant effort. A total area of 0.25 acre of eelgrass was planted.

After allowing additional time for further sediment stabilization within the lagoon, four additional transplant sites (each consisting of 150 planting units) were planted in the east and central basins on August 26, 1998 (Figure 4-1).



**Eelgrass and cordgrass pilot transplant locations**

**Figure 4-1**



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#### 4.1.2 Eelgrass Monitoring

As part of the vegetation mapping described in detail in Chapter 3, the extent of eelgrass was delineated from the high-resolution infrared aerial photographs. The photographs were taken during fall months in 1997, 1998, 1999, 2000, 2001, 2003, 2005, and 2006.

An additional data set is available from May 2005, when eelgrass was monitored acoustically as part of a surveillance project for *Caulerpa taxifolia* and other invasive species in southern California (M&A 2008). Data were collected from a survey vessel using sidescan sonar and plotted on a geo-rectified image of the lagoon. Eelgrass was then delineated to calculate the amount of eelgrass coverage and show its distribution. This method of mapping eelgrass is one of the most efficient and accurate techniques for large areas such as Batiquitos Lagoon.

#### 4.1.3 Cordgrass Planting

Cordgrass was transplanted on April 16 and 17, 1998 at 20 sites in the west, central, and east basins (Figure 4-1). The sites were selected to represent a range of tidal elevations and levels of exposure to wind and waves in order to determine the conditions most favorable to the establishment and expansion of cordgrass. Bare-root cordgrass was collected from the San Diego River Flood Control Channel. Cordgrass was transported to Batiquitos Lagoon in gardening flats covered with damp burlap. The cordgrass was planted as plugs, consisting of two to three cordgrass shoots, 3.3 feet apart along multiple rows perpendicular to the water line at each of the transplant sites. At the time of transplant, the sites were gently sloped, unvegetated mudflats and were established at elevations as low as approximately +2 feet Mean Lower Low Water (MLLW) and as high as +6 feet MLLW. In October 1998, a qualitative assessment of the 20 pilot sites was completed, and nine of the sites were chosen for expansion based on success of the original plantings. Five additional sites were also identified for planting. On October 20, 1998, a second transplant was completed at these five sites. A total of 16,000 ft<sup>2</sup> (0.38 acre) of cordgrass was planted within the lagoon during the two transplant phases.

#### 4.1.4 Cordgrass Monitoring

Cordgrass extent and distribution was monitored using the same infrared photographic methods used for mapping eelgrass. Cordgrass was delineated from photographs taken during fall months in 1998, 1999, 2000, 2001, 2003, 2005, and 2006. In addition to the aerial data, ground-truthing and quantitative assessments of the cordgrass transplant sites were conducted in October 1999, September 2001, and October 2006. At each of the 25 transplant site locations (Figure 4-1), physical data were collected to determine the relative health of the cordgrass. Collected data included canopy height measurements (n=10) and shoot density measurements (n=10).

A small portion of the northeastern shoreline of the central basin was chosen for analysis of growth rates between individual cordgrass clones that grew from seed. Patch radii were measured from the 2001 and 2003 aerial photographs for 14 representative patches. Annual rates of patch expansion were then calculated by subtracting the 2001 patch radii from the 2003 patch radii and dividing by 2. Aerial expansion rates were also calculated.

The physical cordgrass density and canopy height data were graphed and analyzed to assess trends in cordgrass health and recruitment between basins and over the duration of the study. Analyses were performed for each variable (basin and time) independently with one-way



analysis of variance (ANOVA). For analyses, the basin data were grouped across years, and the monitoring year data were grouped across basins. It was not possible to combine the data into a single two-way ANOVA or repeated measures model because of losses of cordgrass transplant areas in the west basin that left only a single representative remaining in 2006. When statistical analyses detected significance for a factor, Tukey's Honestly Significant Difference multiple comparisons test (Tukey's HSD) was used to determine which factor levels differed. Statistical analyses were performed with Statistica 7 software for Windows®.

## 4.2 RESULTS

### 4.2.1 Eelgrass

In October 1997, 0.25 acre of transplanted eelgrass was present in the lagoon (Figure 4-2). By October 1998, 70 to 80 small patches, each approximately 100 ft<sup>2</sup> in size, had recruited into the central basin (Figure 4-3a). Based on the distribution in the southern region of the basin, it appeared that this eelgrass recruited from seed transported from materials planted in the west and central basins. The west and east basins showed a more modest expansion but with obvious growth of new patches. By 1999, eelgrass had expanded to 4.46 acres and was still most abundant in the central basin, where the small patches had expanded clonally to form rings 15 to 30 feet in diameter. In 2000, the smaller patches that had formed during the previous two years grew rapidly, forming relatively continuous beds in all three basins (Figure 4-3b). The west and central basins had reached near maximal levels of eelgrass cover and fluctuated in cover from that point onward (Figure 4-2, Figures 4-3b and c). In the east basin, eelgrass cover continued to expand eastward until 2003 and then fluctuated in cover over the next two sampling intervals.

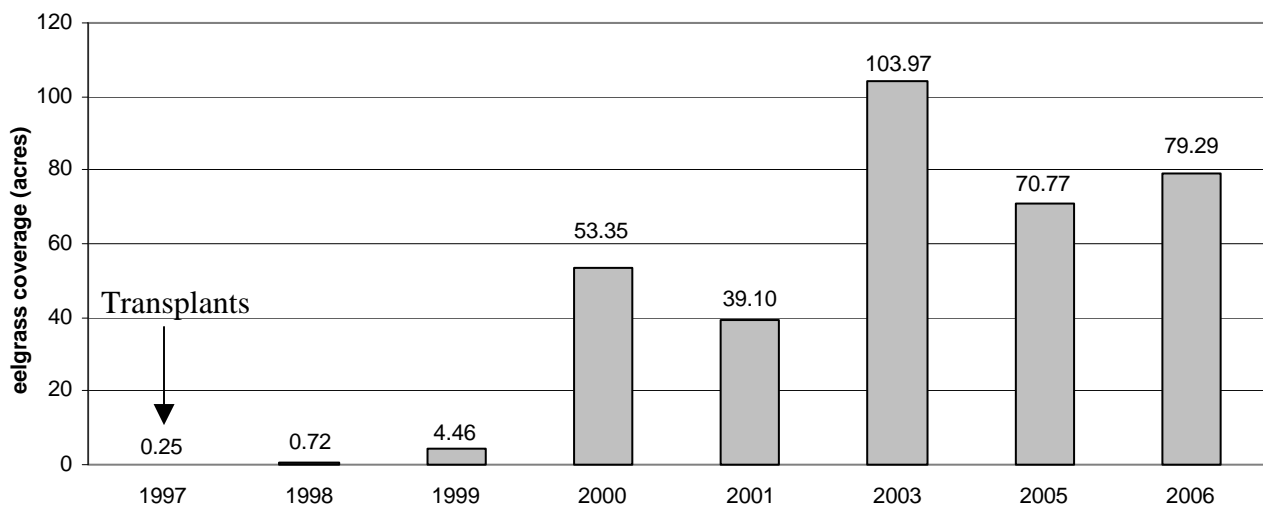
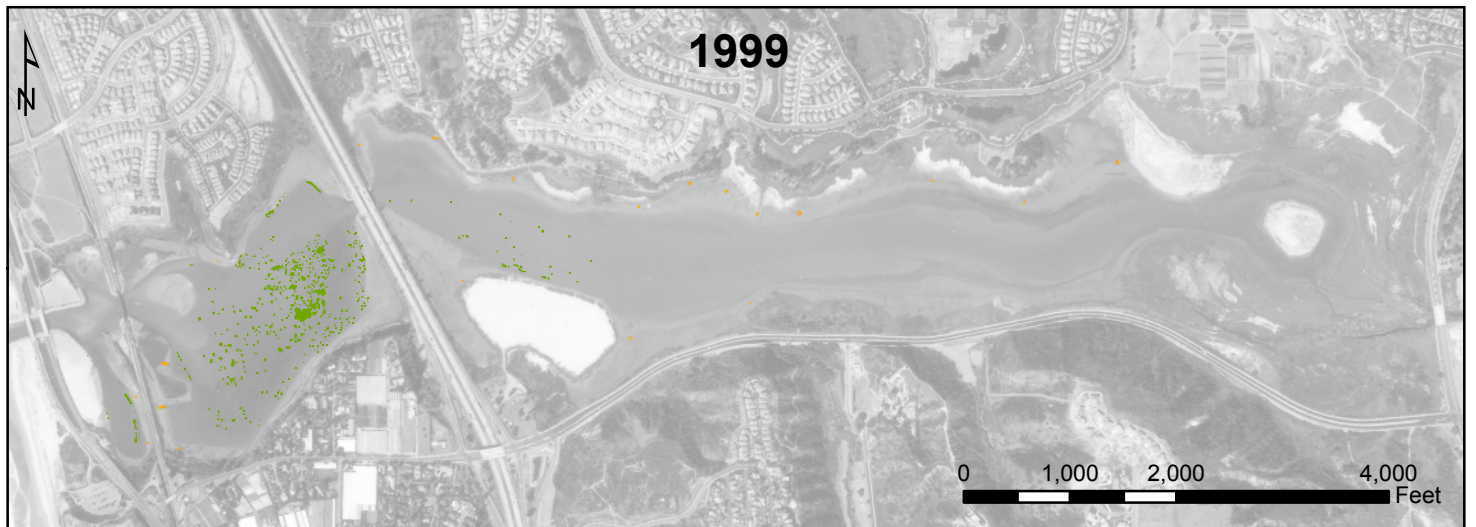
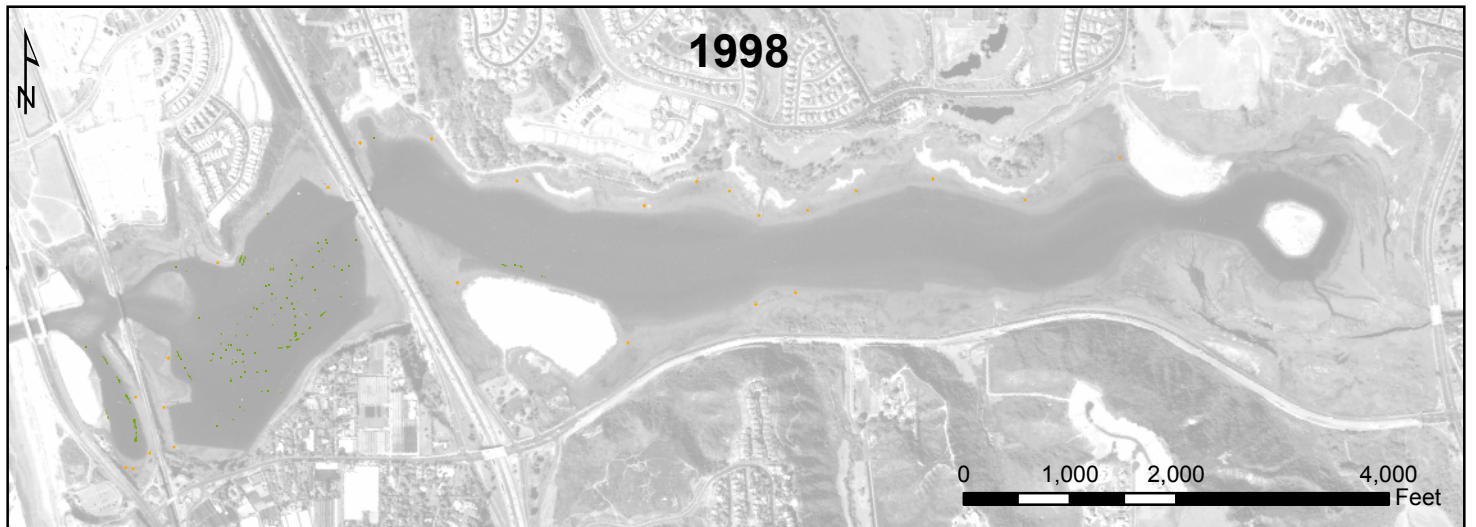
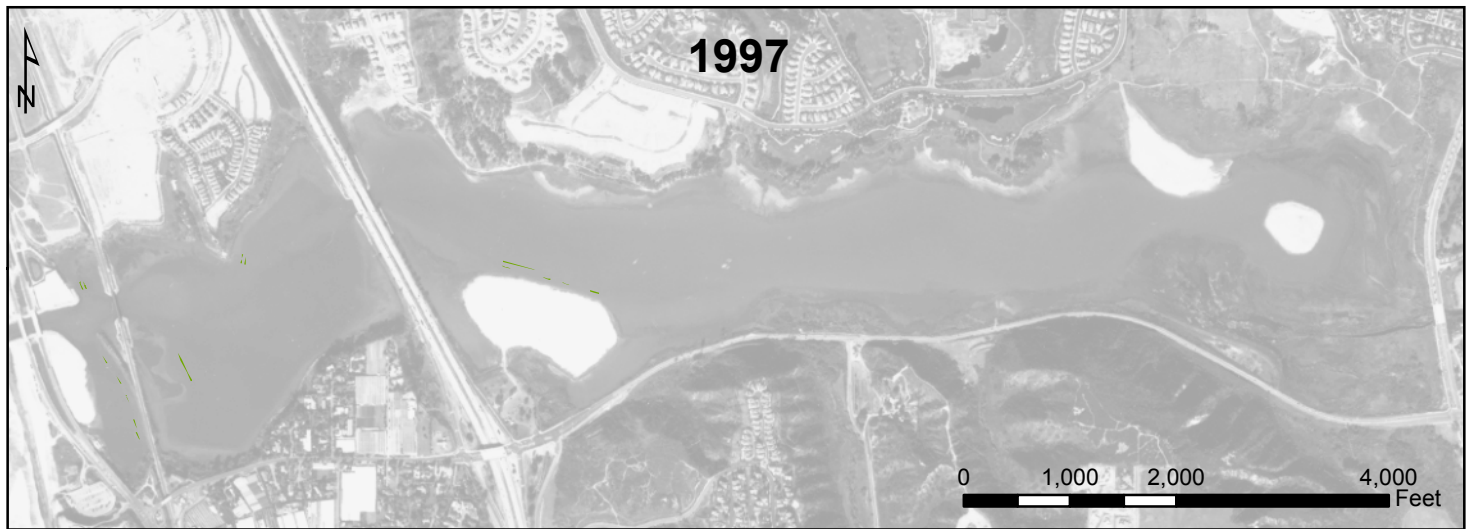
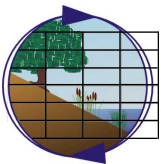


Figure 4-2. Eelgrass coverage (1997-2006).



 Eelgrass  Cordgrass

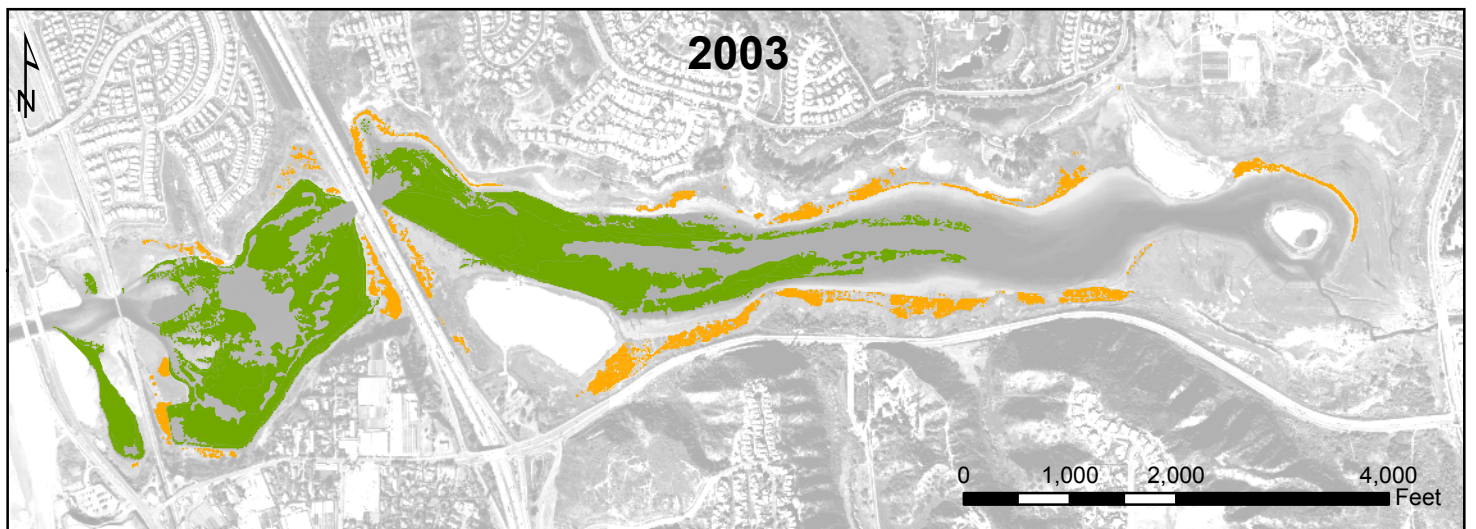
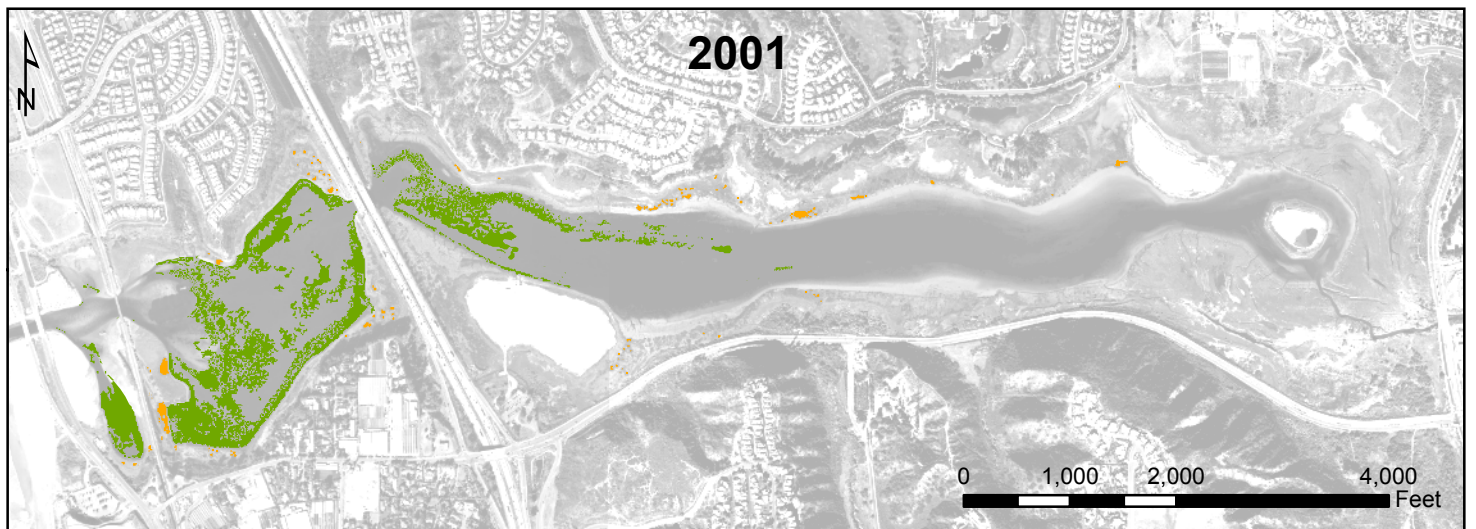
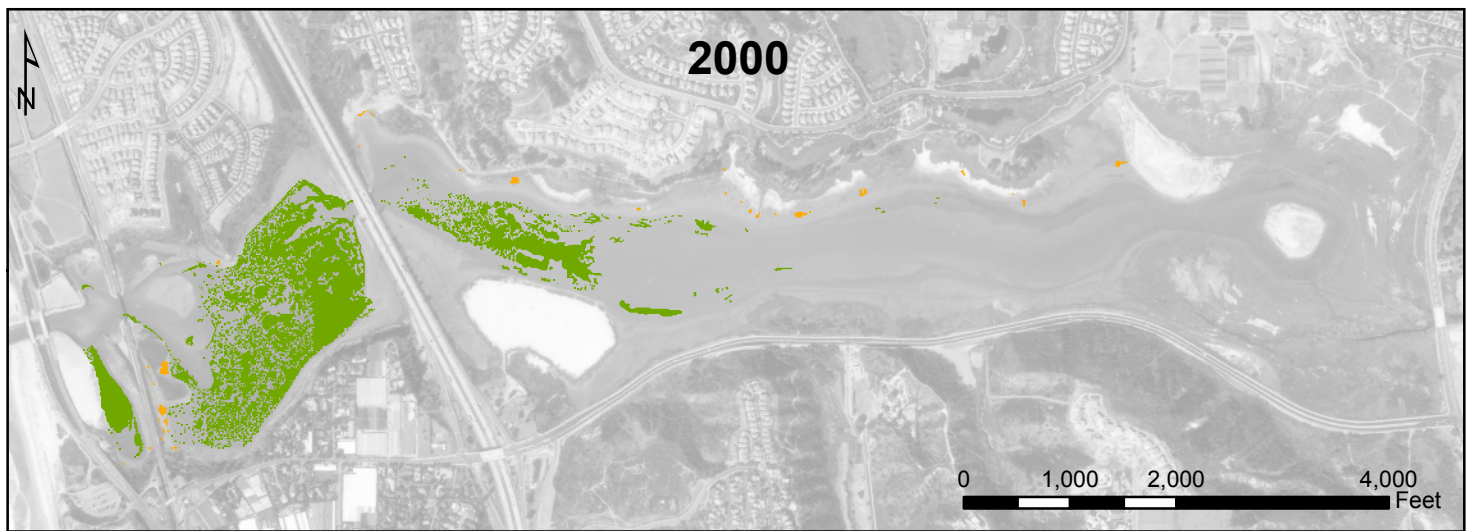


**Pilot revegetation program  
eelgrass and cordgrass distribution (1997, 1998, & 1999)**

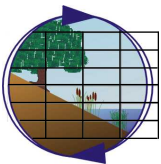
**Figure 4-3a**



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Eelgrass  Cordgrass

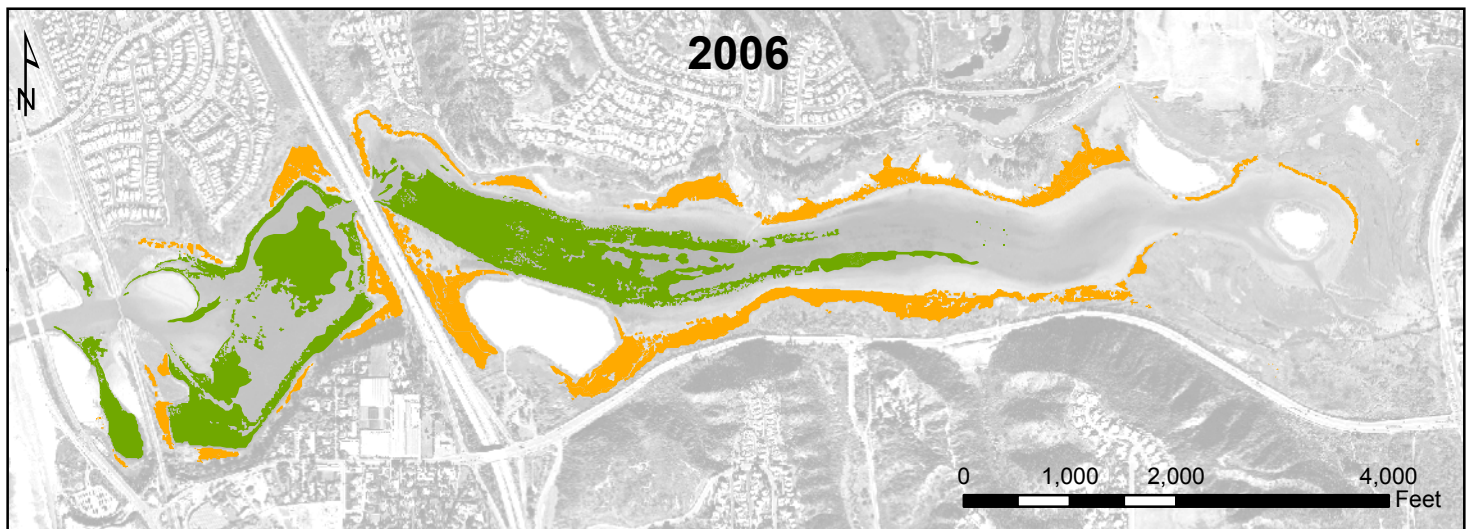
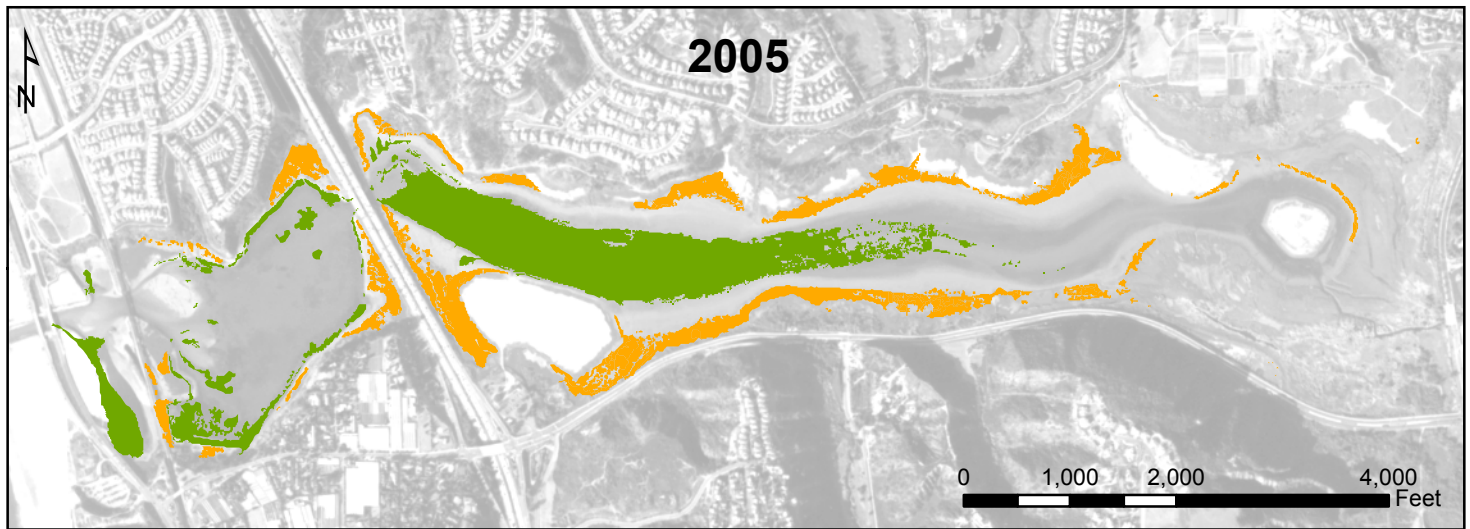


**Pilot revegetation program  
eelgrass and cordgrass distribution (2000, 2001, & 2003)**

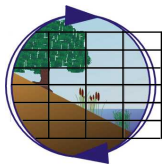
**Figure 4-3b**



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Eelgrass  Cordgrass



**Pilot revegetation program  
eelgrass and cordgrass distribution (2005 & 2006)**

**Figure 4-3c**



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Table 4-1 breaks down the eelgrass coverage by basin. Over the duration of monitoring, the maximum coverage for the west basin was 5.44 acres in 2005. The central and eastern basins attained maximum coverages of 45.20 and 54.95 acres in 2003 and 2005, respectively. Lagoon-wide, eelgrass grew within a tidal range of approximately –5.5 feet to +1.0 foot MLLW, based on 2008 contours. Qualitatively, eelgrass appeared healthy when observed during fish monitoring events. In latter years, eelgrass was sometimes so dense as to make fish monitoring difficult (see Chapter 5). Table 4-1 includes the results from the ancillary acoustic survey performed in May 2005 (2005a), as well as the regularly scheduled aerial mapping in October 2005 (2005b). The amount of eelgrass present in the central basin in the 2005b survey was considerably less than in the 2005a survey. Similar declines were not observed in the east and west basins between these two surveys. They were observed, however, within Agua Hedionda Lagoon during this same period.

**Table 4-1. Eelgrass coverage (acres) by lagoon basin.**

| Year          | 1997        | 1998        | 1999        | 2000         | 2001*        | 2003          | 2005a**       | 2005b***     | 2006         |
|---------------|-------------|-------------|-------------|--------------|--------------|---------------|---------------|--------------|--------------|
| West Basin    | 0.09        | 0.16        | 0.14        | 3.63         | 3.54         | 5.37          | 5.32          | 5.44         | 5.00         |
| Central Basin | 0.07        | 0.52        | 4.08        | 37.22        | 25.91        | 45.20         | 62.12         | 10.38        | 31.94        |
| East Basin    | 0.09        | 0.03        | 0.24        | 12.51        | 9.65         | 53.40         | 52.65         | 54.95        | 42.35        |
| <b>Total</b>  | <b>0.25</b> | <b>0.72</b> | <b>4.46</b> | <b>53.35</b> | <b>39.10</b> | <b>103.97</b> | <b>120.09</b> | <b>70.77</b> | <b>79.29</b> |

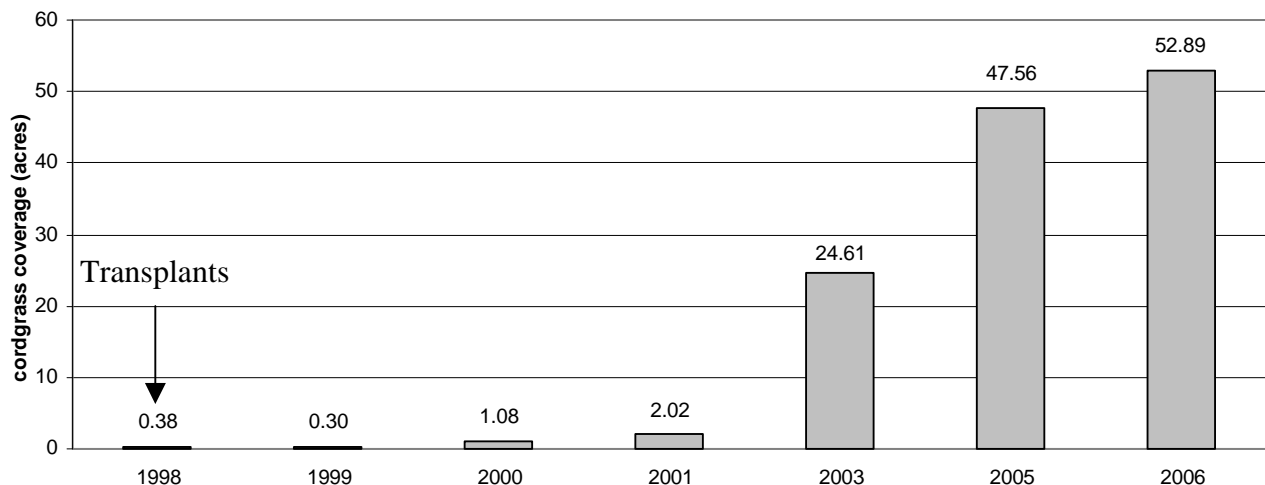
\* Eelgrass coverage in the central basin in 2001 believed to be underestimated due to reduced photographic penetration.

\*\* Additional acoustic survey performed in May 2005

\*\*\*Regular October 2005 aerial mapping event

#### 4.2.2 Cordgrass

Cordgrass expansion from the transplant sites was modest during the first four monitoring years, with the original 0.38 acre of transplanted cordgrass expanding to support 2.02 acres (Figure 4-4, Figure 4-3a, and Figure 4-3b). Initially, there was a slight loss in acreage, as some of the pilot transplanted areas at extreme elevations failed. In the transplant sites that supported cordgrass, however, it was in good health and observed as a mixture of dense stands or areas with sparse young shoots.



**Figure 4-4. Cordgrass coverage (1998-2006).**



Table 4-2 breaks down cordgrass coverage by basin. By 2006, the east basin supported 83% of the total cordgrass in the lagoon.

**Table 4-2. Cordgrass coverage (acres) by lagoon basin.**

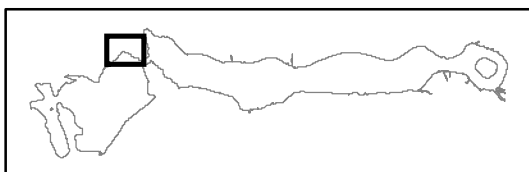
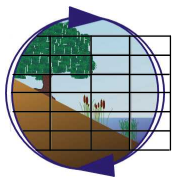
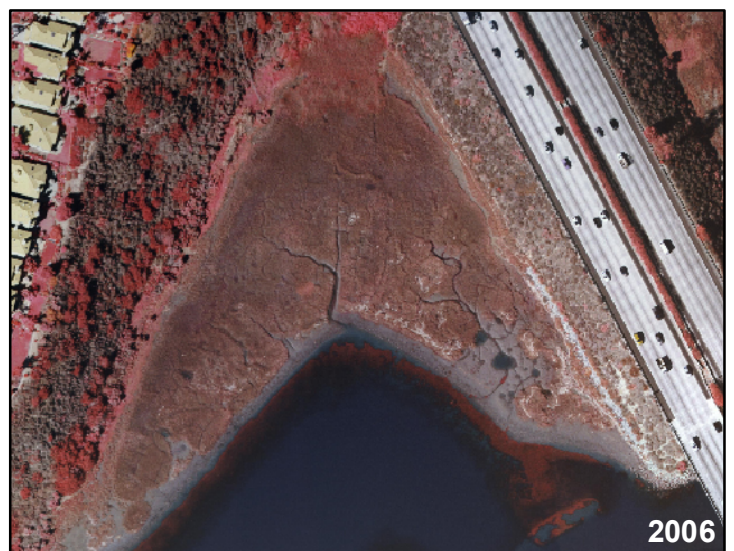
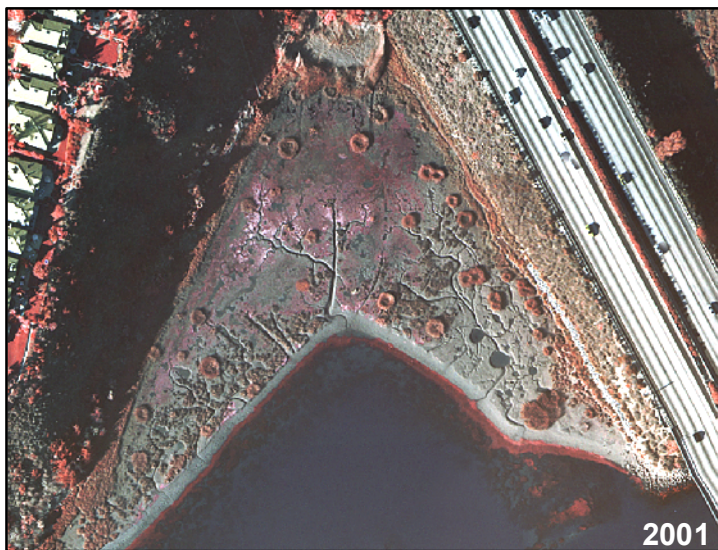
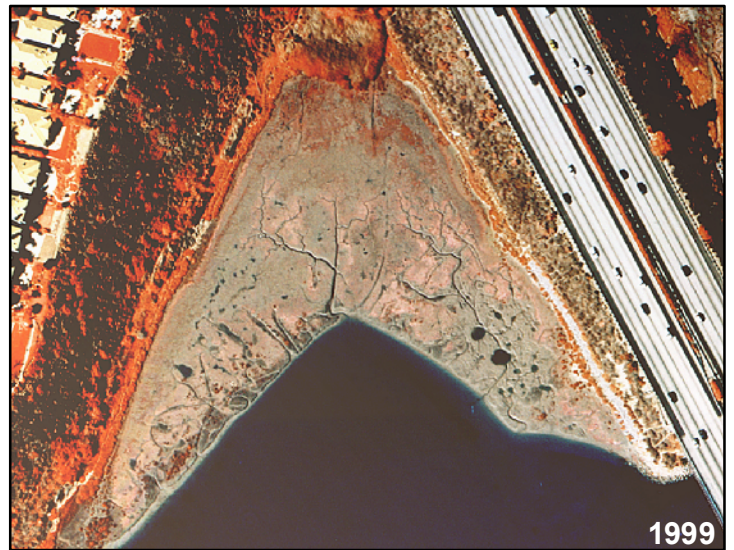
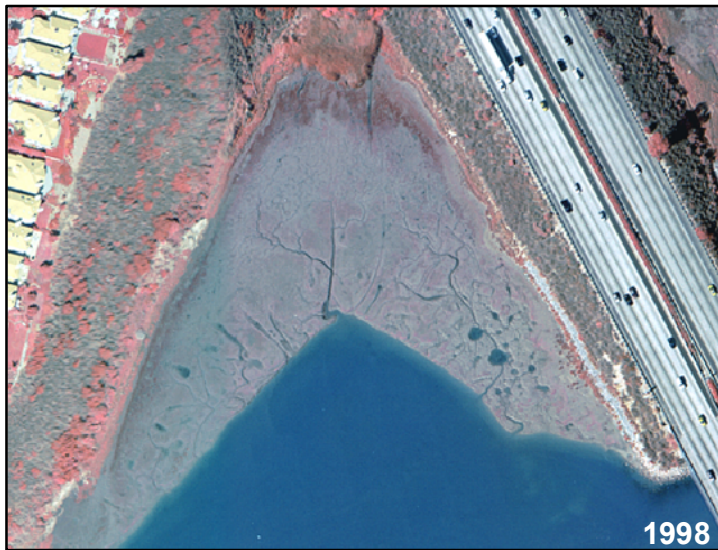
| <b>Year</b>   | <b>1998</b> | <b>1999</b> | <b>2000</b> | <b>2001</b> | <b>2003</b>  | <b>2005</b>  | <b>2006</b>  |
|---------------|-------------|-------------|-------------|-------------|--------------|--------------|--------------|
| West Basin    | 0.06        | 0.01        | 0.02        | 0.06        | 0.04         | 0.04         | 0.04         |
| Central Basin | 0.08        | 0.10        | 0.41        | 1.05        | 4.50         | 8.26         | 9.30         |
| East Basin    | 0.24        | 0.19        | 0.65        | 0.90        | 20.08        | 39.30        | 43.59        |
| <b>Total</b>  | <b>0.38</b> | <b>0.30</b> | <b>1.08</b> | <b>2.02</b> | <b>24.61</b> | <b>47.60</b> | <b>52.93</b> |

Cordgrass was not monitored in year 5 (2002). By year 6 (2003), however, cordgrass had rapidly expanded to cover 24.61 acres (Figure 4-3b). This was more than a 10-fold expansion from 2001. By year 9 (2005), cordgrass had further expanded to fill most of the available habitat around the lagoon and totaled 47.60 acres. In 2006, cordgrass expanded slightly to 52.93 acres (Figure 4-3c) and ranged between approximately +2.5 feet and +6.0 feet MLLW, with a mean elevation of approximately +3.7 feet MLLW. The expansion of cordgrass came at the expense of open mudflat, which was greatly reduced in acreage as cordgrass reached its maximum extent (see Chapter 3).

Localized patterns of cordgrass growth were typical of clonal expansion following a transplant of individual shoot bundles. The observed patterns of growth well beyond the transplant sites indicate that the transplant sites provided seeds. The seeds floated (Huiskes et al. 1995) to, and germinated at, numerous nearby sites. Clonal growth then produced circular patch patterns as cordgrass grew to fill the open mudflat (Figure 4-5). Cordgrass patches established by seedling recruitment near planting transect I expanded at an average rate of  $4.69 \pm 1.11$  feet/year (measured as patch radius expansion) between 2001 and 2003 to fill the open space between patches.

Within the developing cordgrass stands, trends in shoot density were consistent across the monitoring sites. All sites that continuously supported cordgrass experienced increased density between the 1999 and 2001 monitoring events (Figure 4-6). By 2006, all sites where data were collected (in some cases transplant site boundaries were no longer identifiable), cordgrass density had declined from the densities observed in 2001 (Figure 4-6). In 1999, 2001, and 2006, the lagoon-wide cordgrass shoot densities (mean  $\pm$  1 SD) were  $122.2 \pm 80.1$ ,  $351.9 \pm 167.8$ ,  $155.3 \pm 80.8$  shoots/m<sup>2</sup>, respectively. These differences were statistically significant ( $p < 0.001$ ) with Tukey's HSD finding that the 1999 and 2006 monitoring events were similar, yet both different from 2001. There were no significant differences in density among basins ( $p = 0.61$ ). Mean density for all years combined was  $161.8 \pm 69.0$ ,  $220.9 \pm 91.8$ , and  $216.1 \pm 168.8$  shoots/m<sup>2</sup> for the west, central, and east basins, respectively.

Average canopy height (mean  $\pm$  1 SD) varied from a low of  $43.6 \pm 6.8$  cm at east basin transect L in 1999 to a high of  $132.8 \pm 43.2$  cm at east basin transect U in 2006 (Figure 4-7). Generally, cordgrass canopy height ranged from between approximately 80 and 120 cm. The overall average canopy height was  $88.7 \pm 23.3$  cm. Cordgrass canopy height increased lagoon-wide

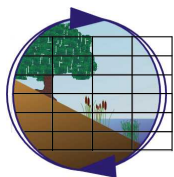
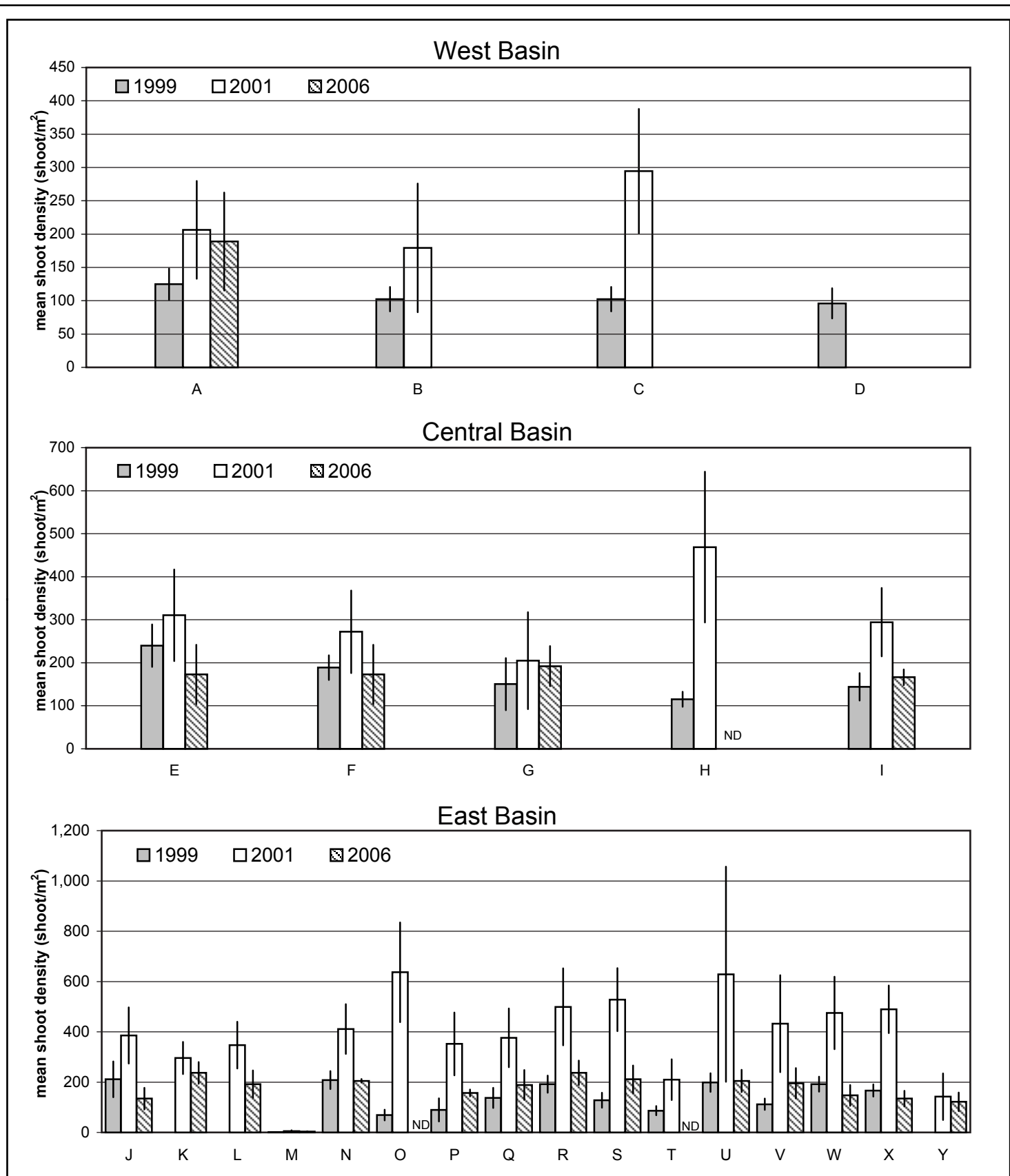


**Example of cordgrass  
expansion from seed**

**Figure 4-5**



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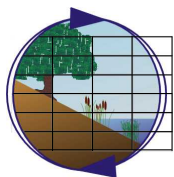
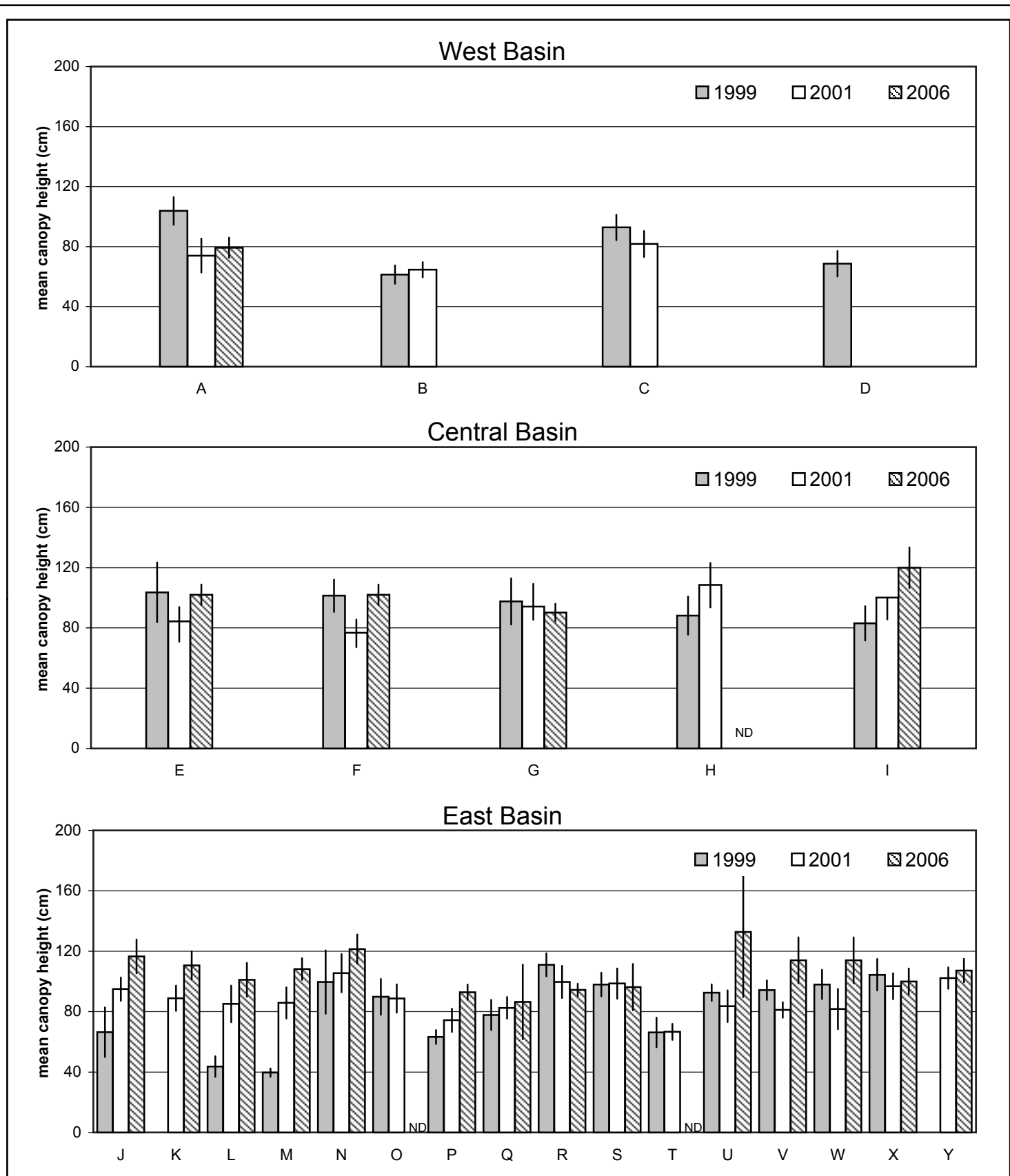


**Mean shoot density of cordgrass (*Spartina foliosa*) ( $\pm 1$  SD)  
within transplanted plots  
October 1999, September 2001, and October 2006**  
ND = no data, cordgrass present but original transplant not recoverable

**Figure 4-6**



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**Mean canopy height of cordgrass (*Spartina foliosa*) ( $\pm 1$  SD)  
within transplanted plots  
October 1999, September 2001, and October 2006**  
ND = no data, cordgrass present but original transplant not recoverable

**Figure 4-7**



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over the three monitoring periods from  $77.8 \pm 30.2$  to  $87.5 \pm 11.8$  and  $104.7 \pm 13.4$  cm, for 1999, 2001, and 2006, respectively. This trend was statistically significant ( $p < 0.001$ ) with Tukey's HSD multiple comparisons test finding that 1999 and 2001 monitoring events were similar, yet both different from 2006. There were no discernable trends among basins ( $p = 0.200$ ) with regard to canopy height. The west, central, and east basins had canopy heights of  $78.3 \pm 14.4$ ,  $96.6 \pm 11.4$ , and  $88.2 \pm 26.4$  cm, respectively.

## 4.3 DISCUSSION

### 4.3.1 Eelgrass

The pilot transplant of eelgrass into Batiquitos Lagoon was successful in that the introduction of eelgrass at the lagoon has resulted in the greatest single intended gain of eelgrass in California and likely the entire Pacific Coast of the United States. The restoration also has been unique in that it is one of only a few system-wide eelgrass introductions ever conducted. The 0.25 acre of eelgrass that was planted at various sites in the lagoon expanded in distribution, with patterns that suggested the planted eelgrass provided seeds to establish patches in nearby areas. These patches grew rapidly, creating expansive eelgrass beds within three years of the planting. Within five years from planting, eelgrass beds covered most of the available habitat, with coverage fluctuating over subsequent years. Eelgrass beds in Batiquitos Lagoon occur between  $-4.5$  feet and  $+0.5$  foot MLLW.

The patterns of eelgrass development and coverage highlight two observations. First, eelgrass expansion can occur rapidly to fill available space if that space is suitable for growth. This was made evident by the time series of maps produced and discussed above. Second, eelgrass can die back abruptly and recover quickly. The second observation results from the discrepancy in eelgrass cover between the acoustic survey performed in May 2005 versus the scheduled aerial mapping in October 2005. Careful review of the acoustic and aerial data indicates that the difference in eelgrass resources in the central basin between the two periods is accurate. Therefore, sometime between the two monitoring events, eelgrass died back significantly in the central basin. This observation is believed to relate to red tide events that occurred during the summer of 2005. Red tides during 2005 were exceptionally dense and prolonged throughout southern California. During this period the red tides at Agua Hedionda Lagoon, located a few miles to the north, were so extreme as to darken the bottom of the lagoon to the degree that diver surveys being undertaken in this system could not be performed for many weeks (M&A unpub. obs.). Extensive eelgrass die-offs occurred at Agua Hedionda Lagoon during this period. It is believed similar die-offs likely occurred within the central basin of Batiquitos Lagoon as well, due to insufficient light reaching the eelgrass canopy at the deeper portions of the central basin.

While eelgrass die-off in Agua Hedionda was more extensive than in Batiquitos Lagoon, the die-back patterns likely differ based on factors of overall lagoon water depths, sediment loading patterns (including watershed contributions during the 2004-2005 winter storms), overall clarity of resident water masses, and turnover rates with the ocean. The pattern of eelgrass die-off in the subsiding and deeper central basin is not surprising when these contributing factors are considered. Most notable in the 2005 variations in eelgrass coverage was the rapid decline in 2005 and recovery by October 2006. This dramatic response may suggest that eelgrass in Batiquitos Lagoon responded to light limitation by shedding aboveground biomass and



recovered from vegetative material by the subsequent fall. Alternatively, it is possible that Batiquitos Lagoon carries such an abundant seed bank that fairly even recovery through seedling germination was possible following the 2005 decline. The aerial photographic mapping techniques used in 2006 do not allow for a determination of recovery mechanisms to be made. Regardless, the observations illustrate the dynamic nature of eelgrass beds, their sensitivity to disturbance, and their ability to recover quickly within Batiquitos Lagoon.

Eelgrass continues to thrive in much of Batiquitos Lagoon and is observed flowering annually. In the west basin, it grows in dense, tall stands. Intruding sands that make much of the basin too shallow to support eelgrass limit its distribution along the shoreline and within the entrance channel. Moreover, tidal current speeds are increased when the intruding sands fill the entrance channel. The increased current speeds may prevent the growth of eelgrass in and along the entrance channel. Additionally, the erosion of the railroad spur has contributed to the deposition of sediments and the loss of eelgrass in the west basin (see Figure 2-9).

In the central basin, eelgrass is likely only limited by the formation of sandbars. The flood shoals raise the seafloor to elevations not suitable for eelgrass growth; however, fringing eelgrass beds eventually form at the base of the shoals (see Figure 2-9). In the shoal areas themselves, eelgrass will be ephemeral and only able to exist following maintenance dredging events.

In the east basin, eelgrass occupies most of the subtidal habitat within the western half of the east basin. Heading east, eelgrass begins to be restricted to the slightly deeper central channel, as the mudflats are too shallow to support eelgrass. Further east, eelgrass ceases to exist altogether. Although the depth of the central channel in the eastern half of the lagoon is sufficient for eelgrass, turbidity likely prevents eelgrass growth. In this portion of the lagoon, wind-driven waves likely cause suspension of fine sediments from the adjacent mudflats. The suspended sediments limit light availability to eelgrass as it is attenuated through the water column. The particles can also directly prevent light absorption when they settle onto eelgrass blades. Under variable turbidity conditions, eelgrass expands and contracts within the deepest portions of the east basin, often leaving narrow fringing beds between the upper desiccation limited tide range and the deeper, light limited depths (Figure 4-3).

Batiquitos Lagoon provides excellent eelgrass habitat. Overall, the mixture of eelgrass, bare bottom, and mudflat provide a diverse mixture of habitats to support an array of fish, invertebrates, and marine birds. Maintaining eelgrass in a dynamic equilibrium with the other habitats should be a priority for resource management. The long-term maintenance of this resource is dependent upon the maintenance of tidal exchange and depth profiles within the lagoon. Tidal exchange is critical to supplying clear water and flushing suspended sediments from the lagoon. Maintaining water depth will also ensure that eelgrass does not become limited by desiccation stress, temperature, turbidity, and poor water quality as more of the lagoon becomes intertidal. These factors are regulated by the maintenance of the lagoon's physical condition. There are signs that the current maintenance-dredging program is not completely adequate for long-term persistence of eelgrass at its present extent. Bathymetric data indicate that much of the eastern basin is becoming shallower over time (See Chapter 2). Currently, maintenance dredging focuses on shoaling areas and the entrance channel. Periodically, it may also be necessary to dredge portions of the east basin to sustain eelgrass-supporting conditions.



#### 4.3.2 Cordgrass

The effort to introduce cordgrass to Batiquitos Lagoon was successful. Cordgrass growth and expansion was not as rapid as was eelgrass, but ultimately large portions of the high-intertidal habitat surrounding the lagoon became populated with cordgrass. Cordgrass expansion began to accelerate four to five years following transplantation. By the sixth post-transplant year, cordgrass had filled most of the suitable habitat. Ultimately, the 0.4 acres of transplanted cordgrass expanded to cover 52.9 acres.

Cordgrass expanded in a smooth pattern without fluctuation in covered areas. The most notable changes in the cordgrass populations throughout the study were relative to the health and appearance of the cordgrass. Cordgrass density increased as cordgrass became established along the lagoon. Then, as cordgrass had nearly filled all of the available space, density began to decline. This was likely the result of intra-specific competition between plants. The colonization of the previously available space meant that numerous juveniles were able to recruit and grow. As the growing individuals began to crowd and compete with one another, density declined. Today, densities likely fluctuate around those observed near the end of the study.

Cordgrass canopy height continued to increase across all basins throughout the study. Unlike the density data, increases in competition may have favored a morphological or genetic drift towards taller blades. The lowered blade density as plants became competitive would have allowed blade lengths to continue to increase as energy was shifted from producing more blades to producing longer blades. Between basins and patches, the ultimate cordgrass canopy height was likely controlled by local site conditions (*sensu* Trnka and Zedler 2000) and intra-specific competition.

Currently, cordgrass appears to have filled all potential habitat around Batiquitos Lagoon. There is relatively little cordgrass in the west basin, likely due more to the shifting sand substrate than the availability of suitable elevations. The presence of cordgrass at Batiquitos Lagoon has provided abundant habitat for the light-footed clapper rail. An increased presence of clapper rails has been documented, and Batiquitos Lagoon has been used as a release site for captive-bred individuals due to the large expanses of available habitat (see Chapter 7).

The restoration of cordgrass at Batiquitos Lagoon represents the largest system-wide restoration of *S. foliosa* in southern California. The sizes and patterns of growth exhibited by patches of cordgrass following planting are noteworthy with regard to future restoration efforts. In 2003, there were identifiable, clonal patches measuring up to 17 meters across. The patches continued to grow to fill the space between them, but they were no longer identifiable as individuals. This illustrates the need for careful selection of donor material during restoration. In continuous beds, it is impossible to determine the extent of a genetic individual without extensive sampling and genetic analysis. To promote genetic diversity within the transplanted population, it is important to widely harvest from donor cordgrass beds across scales that promote genetic diversity among transplant units to reduce susceptibility to disease or genetic weaknesses of a given clone.

At Batiquitos Lagoon, cordgrass expanded to cover tidal ranges between +2.5 feet to +6.0 feet MLLW. The tidal distribution of cordgrass at other transplant sites, however, could be considerably different. The range that it can grow within is more a function of inundation frequency than tidal elevation, which will vary site by site based on tidal muting of the system,



soil drainage characteristics, soil oxidation-reduction potential resulting from inundation duration and soil type, site slope, proximity to channels, organic content of the soil, etc. Therefore, it would be wise to design future restorations at other restored sites to allow for transplanting into a wide range of tidal elevations, to allow site-specific conditions to determine the appropriate elevation for establishment and expansion.

Although the transplant sites were selected to represent a range of tidal elevations and levels of exposure to wind and waves, all but the few transplant sites in the west basin persisted and expanded; therefore, limited conclusions could be drawn about transplant site requirements in relation to wind and wave exposure.

The long-term management of cordgrass at Batiquitos Lagoon is dependent upon maintenance dredging and invasive species management. The buildup of flood shoals has changed the tidal dynamics of each basin (see Chapter 2). Increased tidal lag and muting has prevented water from adequately draining during low tides. This loss of drainage has altered the duration of water inundation at intertidal elevations. Greater inundation of sediments results in an upward movement of the lower extent of cordgrass. Over time, this will result in less cordgrass overall, as the upper limit will not be modified because it is moderated by factors not affected by tidal muting. The result will be lowered carrying capacity for light-footed clapper rail and a decreased supply of primary production to support organisms at higher trophic levels. Keeping accreted sands from restricting tidal flows will help maintain the current distribution of cordgrass.

#### 4.4 RECOMMENDATIONS

To maintain significant and healthy populations of eelgrass and cordgrass in Batiquitos Lagoon, the following recommendations should be considered for implementation.

- The continued maintenance dredging of flood shoals to reduce tidal lag and muting.
- The initiation of a rehabilitation dredging event to deepen channels, maintain sediment traps, and encourage drainage channels across mudflats to improve hydrodynamic functions relating to water quality and to reverse whole-basin accretion.
- The completion of periodic monitoring and mapping (every five years) of eelgrass and cordgrass populations to determine population status and health.
- The inclusion of searches for invasive species of cordgrass and *Caulerpa* during the periodic invasive species surveillance recommended in Chapter 3.



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